23

ARR No. E5E16

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

May 1945 as
Advance Restricted Report E5E16

EFFECT OF OIL FLOW TO PISTON ON PISTON-RING STICKING AND OIL CONSUMPTION IN A SINGLE-CYLINDER ENGINE

By Max J. Tauschek, Lester C. Corrington
and John B. Meigs

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

WASHINGTON

E-75

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

EFFECT OF OIL FLOW TO PISTON ON PISTON-RING STICKING AND OIL CONSUMPTION IN A SINGLE-CYLINDER ENGINE

By Max J. Tauschek, Lester C. Corrington
and John B. Meigs

SUMMARY

Object. - To determine the effect of the amount of oil flow to the piston on the ring-sticking characteristics of a piston and ring assembly and on the engine oil consumption.

Scope. - Two series of tests were run with the oil supplied to the piston by means of a single fixed nozzle. The first series was run at a constant inlet-air pressure of 56 inches of mercury absolute with oil-flow rates to the piston of 2.0 and 5.75 pounds per minute. The tests of the second series were begun at an inlet-air pressure of 35 inches of mercury absolute, which was gradually increased throughout the test, and were run with constant oil-flow rates ranging from 0.2 pound to 5.0 pounds per minute. An unpublished test from another investigation provides data to evaluate the effect of changing the point of oil-jet impingement on the ring-sticking time.

Summary of results. - The results show that for the engines and oil systems tested:

1. With one oil nozzle directed vertically upward at the under side of the piston crown, the higher flow rates necessary to appreciably increase the ring-sticking time were accompanied by large increases in oil consumption in the range of piston temperatures experienced in these tests.

2. When two nozzles were used on opposite sides of the cylinder, each directed toward the lower part of the cylinder barrel, one test showed considerably improvement over tests using a single nozzle directed vertically upward on a ring-sticking and scuffing basis.

3. When a nozzle was directed vertically upward at the under side of the piston crown, an oil-flow rate of about 2 pounds per minute was found to be nearly optimum for the engine tested on the basis of minimum specific oil consumption, ring breakage, and ring wear throughout the duration of a ring-sticking test.

INTRODUCTION

During the general program requested by the Army Air Forces relative to increasing the power output of the Allison V-1710 engine, several failures in piston and ring assemblies have occurred at the Cleveland laboratory of the NACA. These failures have manifested themselves as broken and stuck piston rings and, in a more severe form, as burned and scored pistons.

At the time of these failures, four main factors were considered as possible causes leading to the ultimate destruction of the piston: (1) preignition, (2) lack of sufficient piston clearance, (3) progressive piston-ring failure, and (4) inadequate piston cooling. Subsequent work indicated that factors (1) and (2) accounted for practically all of the failures encountered during the experimental investigation. The relation of piston-ring failure to destruction of the piston has been discussed in reference 1.

The tests reported herein were carried out from December 1943 to June 1944 to determine quantitatively the effect of increased cooling and lubrication of the piston and ring assembly with additional oil as a means toward extending the engine-operating time until incipient piston-ring failure occurs through sticking. Changes in oil consumption accompanying the changes in the amount of oil supplied to the piston were also investigated.

APPARATUS AND TEST PROCEDURE

The tests were conducted on a single cylinder from an Allison V-1710 engine mounted on a CUE crankcase. Oil was metered to the piston by a nozzle installed in the engine and directed vertically upward so as to strike the under side of the piston crown near the major-thrust face. The oil flow was controlled by varying the size of the nozzle and by regulating the oil pressure at the nozzle. In order to prevent bearing throw-off oil from reaching the piston, a baffle cut to accommodate the connecting rod was installed between the engine crankcase and the cylinder assembly.

Two oil systems were used in tests of another program; the results of these tests were used to provide data to evaluate the effect of changing the point of oil-jet impingement on the ring-sticking time. The first oil system was similar to the one just described. In the second oil system, two nozzles, one on the major- and one on the minor-thrust side of the cylinder, were so directed that the oil struck the cylinder wall about one-third of the distance up from the bottom of the barrel.

Two series of tests were conducted. Clean, used pistons, fitted with new piston rings, were used in the first series of tests. Each test of the second series was begun with a new piston and ring assembly to eliminate the condition of the piston as a variable. For all the tests, compression rings of standard rectangular cross section were used; the top ring was beveled along its upper edge and the second and the third rings were taper-faced. This arrangement of rings is standard in some models of the Allison V-1710 engine. Piston rings were selected that conformed as closely as possible to the following specifications:

Ring	Diametral tension (lb)	Side clearance (in.)	Compressed end gap (in.)
Top compression	9.0	0.006	0.035
Second compression	8.3	.005	.035
Third compression	8.3	.004	.035
Dual oil	---------	.003	.035

Tests were conducted with cylinders that had been used for some time previous to the ring-sticking tests because it was found in previous tests that operation with a newly honed barrel prolonged the time required for ring sticking.

Because the time at which ring sticking took place was to be judged by the extent of blow-by past the piston, the crankcase was sealed prior to the tests and a displacement-type gas meter was connected to the crankcase outlet. A water manometer was used to measure the gas pressure in the crankcase. During the tests it was found to be more convenient to use the crankcase pressure as the criterion of ring sticking because the crankcase-pressure manometer gave an instantaneous indication of increased blow-by. A pressure of 10 inches of water usually indicated sticking of the top ring.

Each test was preceded by a standard run-in of $7\frac{1}{4}$ hours' duration in accordance with the Army Air Forces Technical Order No. 02-1-4, dated January 19, 1943, for the Allison V-1710 engine. In the case of the constant-power series, the engine was operated an additional

3 hours with an inlet-air pressure of 42.5 inches of mercury absolute in order to insure that the engine was properly run in for immediate high power operation. An oil-flow rate to the piston of 2.0 pounds per minute was used for all run-in operations.

The first series of tests was conducted at constant high power output with an oil-flow rate to the piston of 2.0 pounds per minute for one test and 5.75 pounds per minute for the second test. Operating conditions held constant were:

Inlet-air pressure, inches mercury absolute	56
Engine speed, rpm	2600
Fuel-air ratio	0.085
Inlet-air temperature, °F	200
Compression ratio	6.65
Inlet-oil temperature, °F	185
Coolant-outlet temperature, °F	250
Spark advance, degrees B.T.C.:	
Inlet	28
Exhaust	34

The second series of tests followed a procedure which was developed in connection with a previous ring-sticking program and which gave very satisfactory results. These tests were begun at an inlet-air pressure of 35 inches of mercury absolute and this pressure was raised 0.2 inch every half hour until ring sticking occurred.

Constant operating conditions for the second series of tests were as follows:

Engine speed, rpm	2600
Fuel-air ratio	0.085
Inlet-air temperature, °F	250
Compression ratio	6.65
Inlet-oil temperature, °F	185
Cooling-outlet temperature, °F	250
Spark advance, degrees B.T.C.:	
Inlet	28
Exhaust	34

All the tests were run with AN-F-28, Amendment-2, fuel and with Navy 1120 oil. Water was used in the coolant system, which was so pressurized that the coolant could be operated at temperatures above the normal boiling point.

Complete data were taken at 1/2-hour intervals during all the tests. The tests were terminated when an increase in crankcase pressure to 10 inches of water indicated that ring sticking had taken place. Early in the investigation it was found that engine shutdowns during a test prolonged the running time required for ring sticking to occur. Consequently, the greater part of the test work was carried out on a 24-hour basis, the tests being run with as few interruptions as possible.

RESULTS AND DISCUSSION

The engine running time required to bring about a condition of ring sticking is mainly dependent upon the fuel, the lubricating oil, and the temperature of the piston-ring belt. (See reference 2.) With the fuel and the oil eliminated as variables, the time required for ring sticking to occur becomes mainly a function of piston temperature and any change in engine operating conditions that affects this temperature will exert a corresponding effect on the ring-sticking tendencies.

In the tests reported herein, the range of piston temperatures occurring through changes in the power level of the engine was varied between tests by controlling the quantity of oil directed against the piston. Changes in this quantity of oil, however, also affect the amount of oil circulated through the ring grooves and, because of the natural detergency of the oil, which holds the ring-sticking materials in suspension (reference 3), this factor tends to change the ring-sticking time. Another possible effect of changes in this quantity of oil might be the effect on ring movement, which may wear away the ring-groove deposits (reference 4).

Results of ring-sticking tests. - Figures 1, 2, and 3 illustrate typical failures caused by ring sticking that were encountered during the tests. Ring sticking was found to occur invariably on the minor-thrust side of the piston.

The effect on running time of variations in the amount of oil supplied to the piston is shown in figure 4 and tables 1 and 2. The curve in figure 4 for the first series of tests was drawn approximately parallel to that for the second series of tests because the data from the first tests were insufficient to define accurately the entire curve. The curve for the second series of tests shows little variation in running time as the oil flow is increased from 0.2 pound to about 2.0 pounds per minute, after which the running time begins to increase. These results are similar to those reported by Glaser in reference 2, in which the oil flow to the cylinder was varied by changing the engine oil pressure.

Blow-by. - Figure 5 shows a typical example of how the blow-by rate past the piston varies as the test progresses and also illustrates the variation in crankcase pressure for the same test. The marked increase in rate of blow-by accompanying ring sticking is readily apparent from figure 5. During the tests no attempt was made to differentiate between different degrees of ring sticking. Because the degree of ring sticking determined the rate of blow-by and the crankcase pressure to a large extent, an arbitrary limit was set on the degree of ring sticking at the end of the run by setting an arbitrary limit on the crankcase pressure.

Lubrication. - Variations in the amount of oil directed against the piston not only altered the piston temperature but also resulted in changes in the lubrication of the piston and ring assembly. The additional lubrication that reached the ring groove probably had a bearing on the ring-sticking tendencies, principally through the detergency of the additional oil and through possible changes in the ring movement, as mentioned previously.

With the two lowest oil flows used in the tests, there is evidence to believe that the lubrication of the piston and ring assembly was inadequate. In some of these tests the pistons were found to be scuffed and the rings fractured. Figure 2 shows a piston taken from a test run with 0.2-pound-per-minute oil flow. A part of the second ring has been broken away and scuff marks are visible near the wrist-pin boss.

Oil consumption. - The variation in brake specific oil consumption with test running time for each of the oil-flow rates is presented in figure 6. The curves show that, at the two lowest oil flows, the brake specific oil consumption remains practically constant for the first 12 to 14 hours, after which it begins to rise gradually. The curves for the two highest oil flows continue to drop until the end of the test, indicating that the run-in condition of the rings improved during the entire test period.

The data at the 6-hour point in figure 6 have been replotted to obtain figure 7. The 6-hour point was chosen because the rings were probably fairly well run in by this time in most cases and had not been run long enough to be appreciably worn. The curve in figure 7 indicates that, at oil-flow rates in excess of about 2 pounds per minute, the brake specific oil consumption at the 6-hour point begins an upward trend. At an oil flow of 5 pounds per minute the brake specific oil consumption is about 0.025 pound per brake horsepower-hour.

Method of supplying oil. - In all the preceding tests the oil was supplied to the piston by a nozzle directed vertically so that the oil stream struck the under side of the piston crown on the major-thrust side. No attempt was made to determine the effects of relocating this nozzle or of installing additional nozzles on the ring-sticking tendencies of the engine.

The importance of the position and the number of the oil-supply nozzles was demonstrated by unpublished data obtained during another investigation involving widely varying operating conditions, many of which included operation at extremely high power output. The engine used for the test comprised a multicylinder Allison block set up to fire one cylinder (reference 5) and a piston and ring assembly incorporating a keystone top ring. In all other respects it was similar to the engine used to obtain the data for this report, with the exception that the baffle plate used to prevent bearing throw-off oil from reaching the piston was not incorporated in the setup. Operation of this engine for periods ranging between 5 and 15 hours with oil-flow rates to the oil nozzle of about 7 to 8 pounds per minute resulted in ring sticking and, upon removal of the piston assembly, the rings were often found to be broken and the piston and rings badly scuffed. The condition was greatly relieved when the oil-supply system was revised to include two nozzles, each so located that the oil was directed against the barrel about one-third of the distance up from the bottom. During the lower part of the stroke the oil therefore impinged on the piston, and during the upper part of the stroke the oil impinged on the barrel. One nozzle supplied the major-thrust side and the other supplied the minor-thrust side.

The first piston, operated with this revised oil system and with an oil-flow rate of 2 pounds per minute through each nozzle, was run a total of 41 hours when the test was stopped owing to a connecting-rod failure. An examination of the rings at the end of this test showed them to be in excellent condition. The oil consumption during the run was about 0.019 pound per brake horsepower-hour.

From the foregoing statements, it can be seen that the method of supplying oil to the piston and cylinder is quite critical with regard to ring sticking and this fact must be recognized in any attempt to compare the tests of this report with other data.

SUMMARY OF RESULTS

The results of tests made on a single cylinder from an Allison V-1710 engine with variable oil-flow rates to the piston from a single fixed nozzle, and of tests made on a multicylinder Allison block with two different oil systems, show that, for the engines and oil systems tested:

1. With one oil nozzle directed vertically upward at the under side of the piston crown, the higher flow rates necessary to appreciably increase the ring-sticking time were accompanied by large increases in oil consumption in the range of piston temperatures experienced in these tests.

2. When two nozzles were used on opposite sides of the cylinder, each directed toward the lower part of the cylinder barrel, one test showed considerable improvement over tests using a single nozzle directed vertically upward on a ring-sticking and scuffing basis.

3. When a nozzle was directed vertically upward at the under side of the piston crown, an oil-flow rate of about 2 pounds per minute was found to be nearly optimum for the engine tested on the basis of minimum specific oil consumption, ring breakage, and ring wear throughout the duration of a ring-sticking test.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. Tauschek, Max J., and Corrington, Lester C.: Effect of Progressive Ring Failure on Piston Destruction. NACA ARR No. E5B07, 1945.

2. Glaser, Wolfgang: Der Einfluss der Betriebsbedingungen auf das Kolbenringstecken bei der Betriebstoffdauerprüfung. Luftfahrtforschung, Bd. 16, Lfg. 8, 20, Aug. 1939, pp. 438-446.

3. Talley, S. K., and Larson, R. G.: Lubricating Oil Detergency. Ind. and Eng. Chem. (Anal. ed.), vol. 15, no. 2, Feb. 15, 1943, pp. 91-95.

4. Lahiri, A., and Mikolajewski, Fl/Lt.: Investigation of Piston Ring Sticking and Analysis of Ring Groove Deposits. Rep. No. E3989, R.A.E. (British), Nov. 1943.

5. Waldron, C. D., and Biermann, A. E.: Method of Mounting Cylinder Blocks of In-Line Engines on CUE Crankcases. NACA RB No. E4G27, 1944.

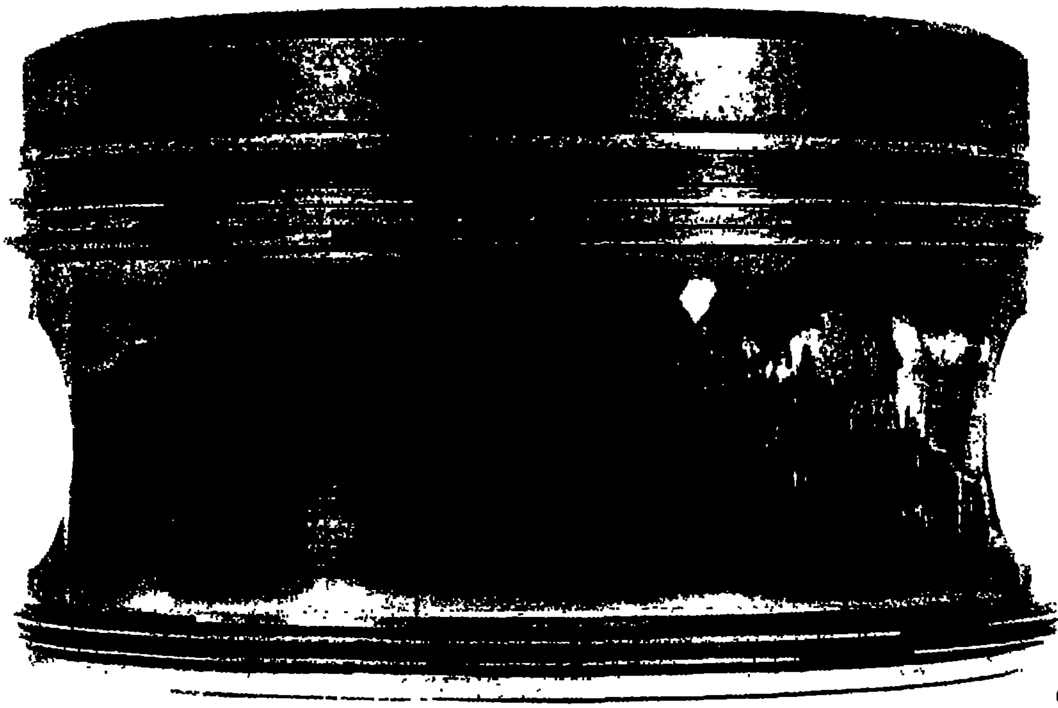
TABLE 1. - EFFECT OF OIL FLOW TO PISTON ON RING-STICKING TIME AT CONSTANT POWER

Oil flow to piston (lb/min)	Brake mean effective pressure (lb/sq in.)	Test running time (hr)
2.0	260 to 275	9.5
5.75	260 to 275	15.0

TABLE 2. - EFFECT OF OIL FLOW TO PISTON ON RING-STICKING TIME WITH VARIABLE POWER

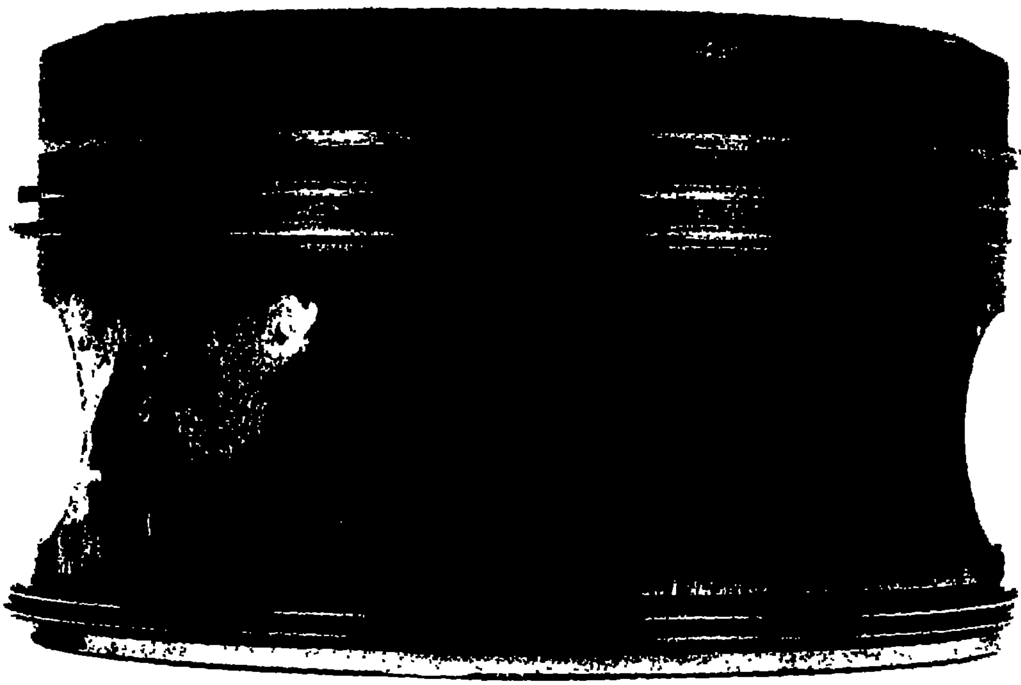
Oil flow to piston (lb/min)	Number of tests	Ring-sticking time (hr)	Average ring-sticking time (hr)	Average oil consumption at 6 hours (lb/bhp-hr)
0.2	3	24.8 25.4 24.3	24.8	0.005
0.6	3	24.6 27.2 24.0	25.3	0.006
2.0	3	27.3 21.3 25.8	24.8	0.008
5.0	4	27.0 27.4 33.4 35.4	30.8	0.025

National Advisory Committee
for Aeronautics



(a) Major-thrust face.

Figure 1. - Piston operated for 25.8 hours with an oil-flow rate of 2.0 pounds per minute. The sticking of the top compression ring is typical in degree and location of those encountered during the ring-sticking tests.



(b) Minor-thrust face.

Figure 1. - Concluded.

Figure 2. - Major-thrust face of piston operated for 24.8 hours with an oil-flow rate of 0.2 pound per minute. Scuff marks are visible near the wrist-pin boss and a piece is broken from the second compression ring.

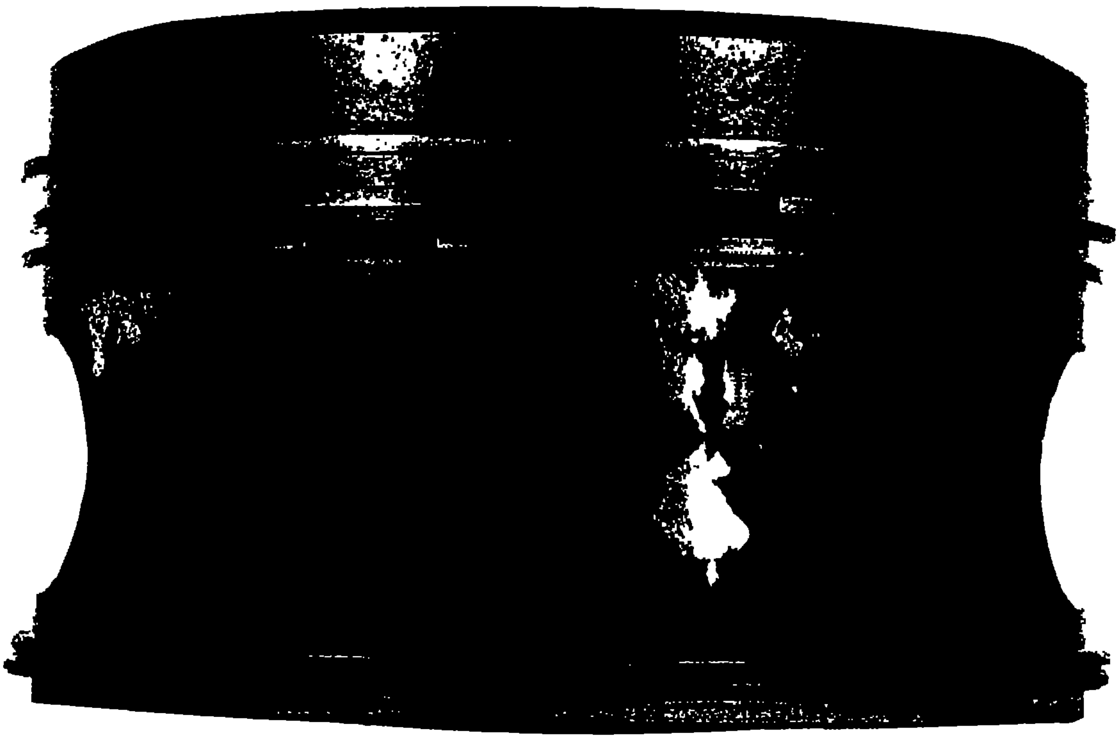


Figure 3. - Minor-thrust face of piston operated for 35.4 hours with an oil-flow rate of 5.0 pounds per minute.

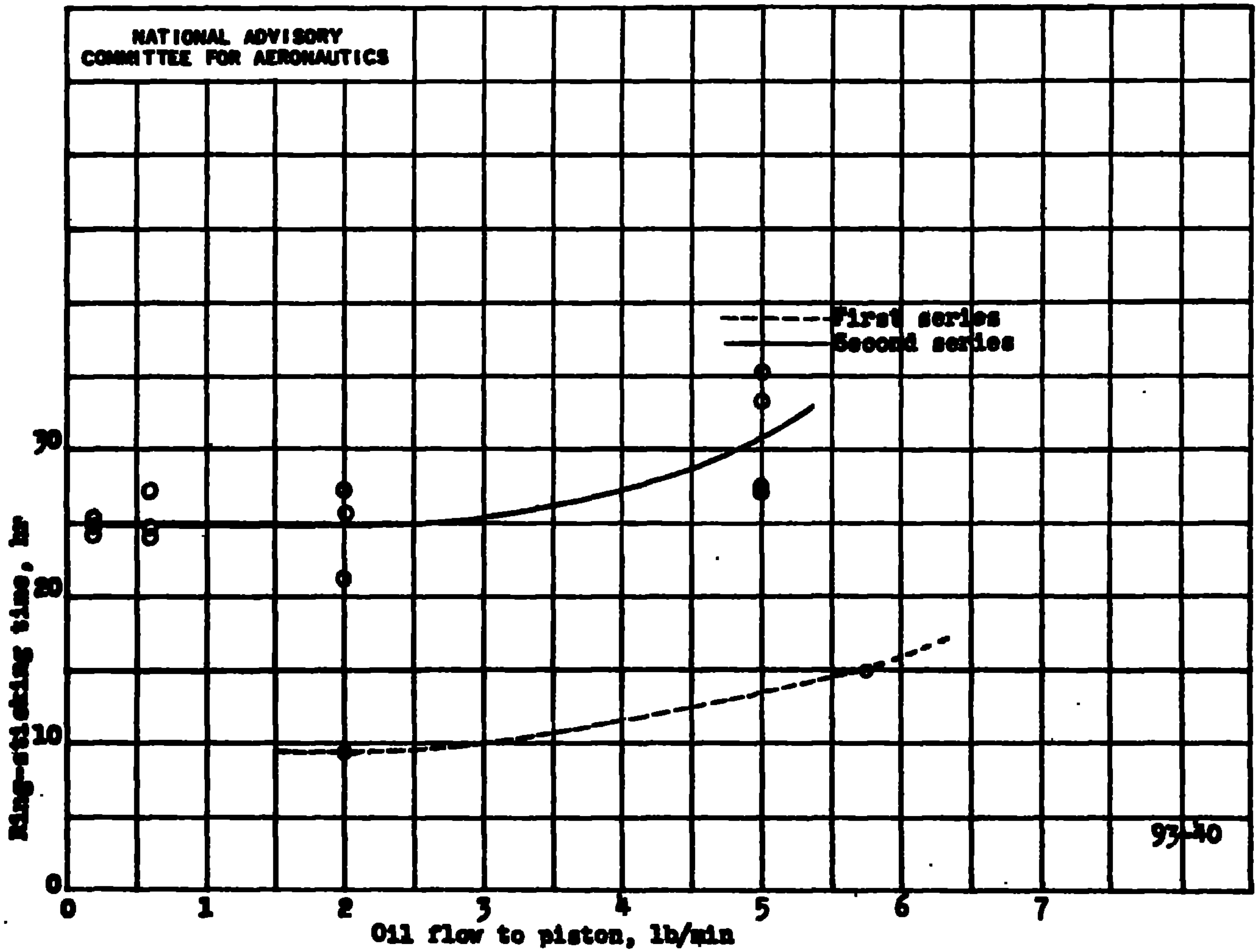


Figure 4. - Effect of oil flow to piston on ring-sticking time. Engine speed, 2600 rpm; inlet-air pressure: first series, 56 inches of mercury absolute; second series, 35 inches of mercury absolute plus 0.2 inch of mercury every half hour; fuel-air ratio, 0.085; inlet-oil temperature, 185° F; coolant-outlet temperature, 250° F; inlet-air temperature: first series, 200° F; second series, 250° F.

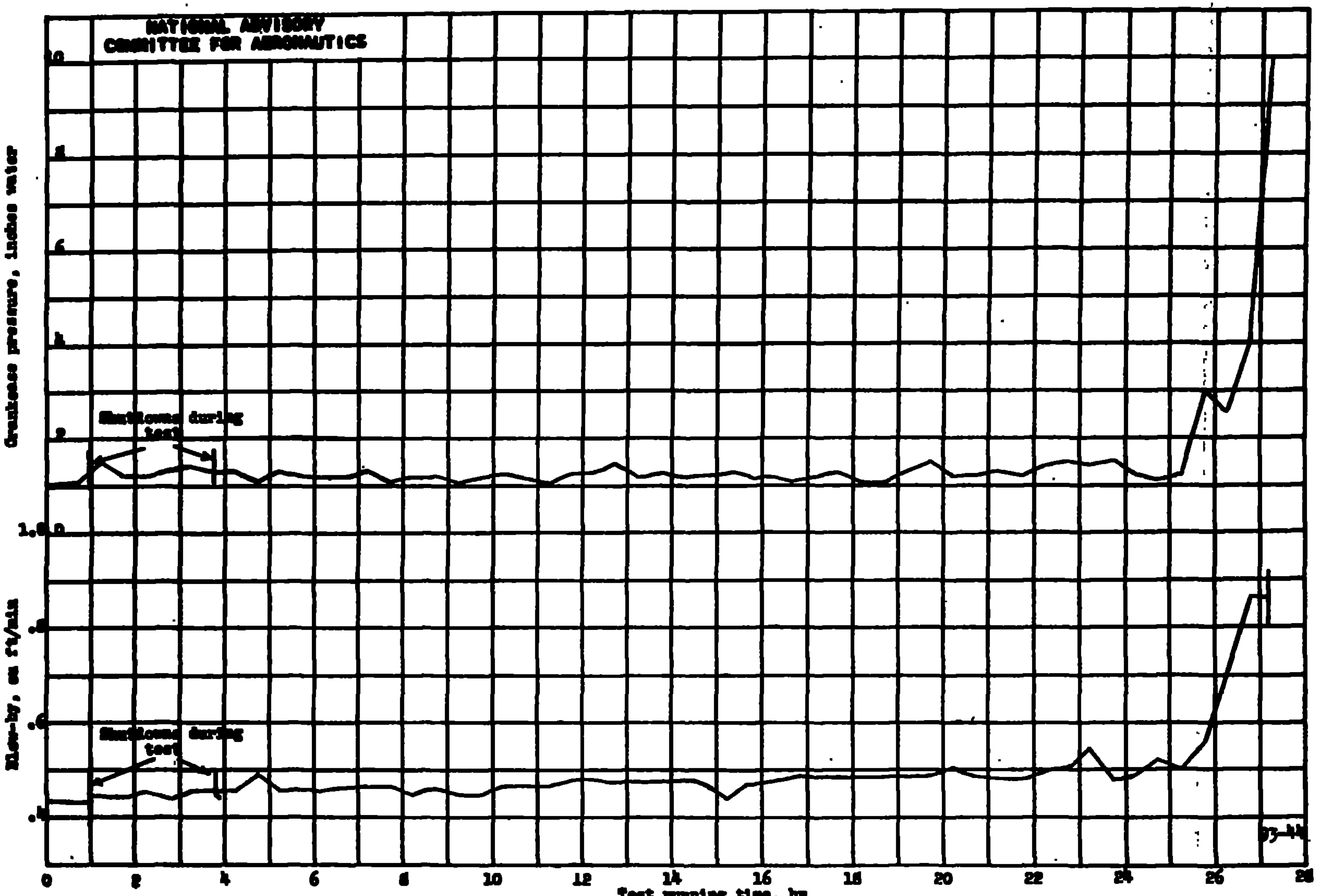


Figure 5. - Variation of crankcase pressure and rate of blow-by with test running time. Engine speed, 2600 rpm; inlet-air pressure, 35 inches of mercury absolute plus 0.2 inch of mercury every half hour; fuel-air ratio, 0.085; inlet-oil temperature, 185° F; coolant-outlet temperature, 250° F; inlet-air temperature, 250° F; oil flow to piston, 0.6 pound per minute.

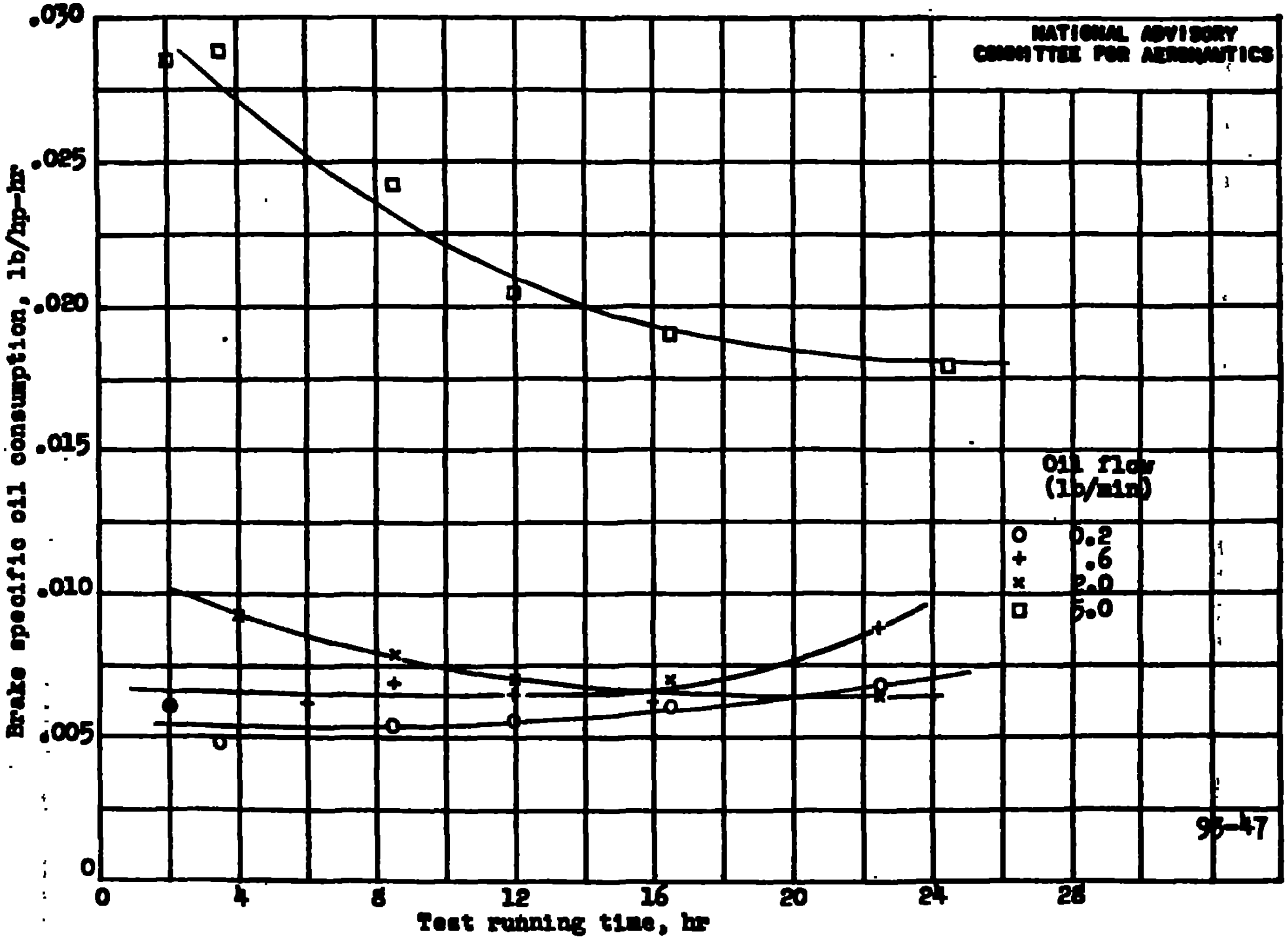


Figure 6. - Effect of test running time on brake specific oil consumption. Values calculated from the average oil consumption for all the tests for each oil flow used. Engine speed, 2600 rpm; inlet-air pressure, 35 inches of mercury absolute plus 0.2 inch of mercury every half hour; fuel-air ratio, 0.085; inlet-oil temperature, 185° F; coolant-outlet temperature, 250° F; inlet-air temperature, 250° F.

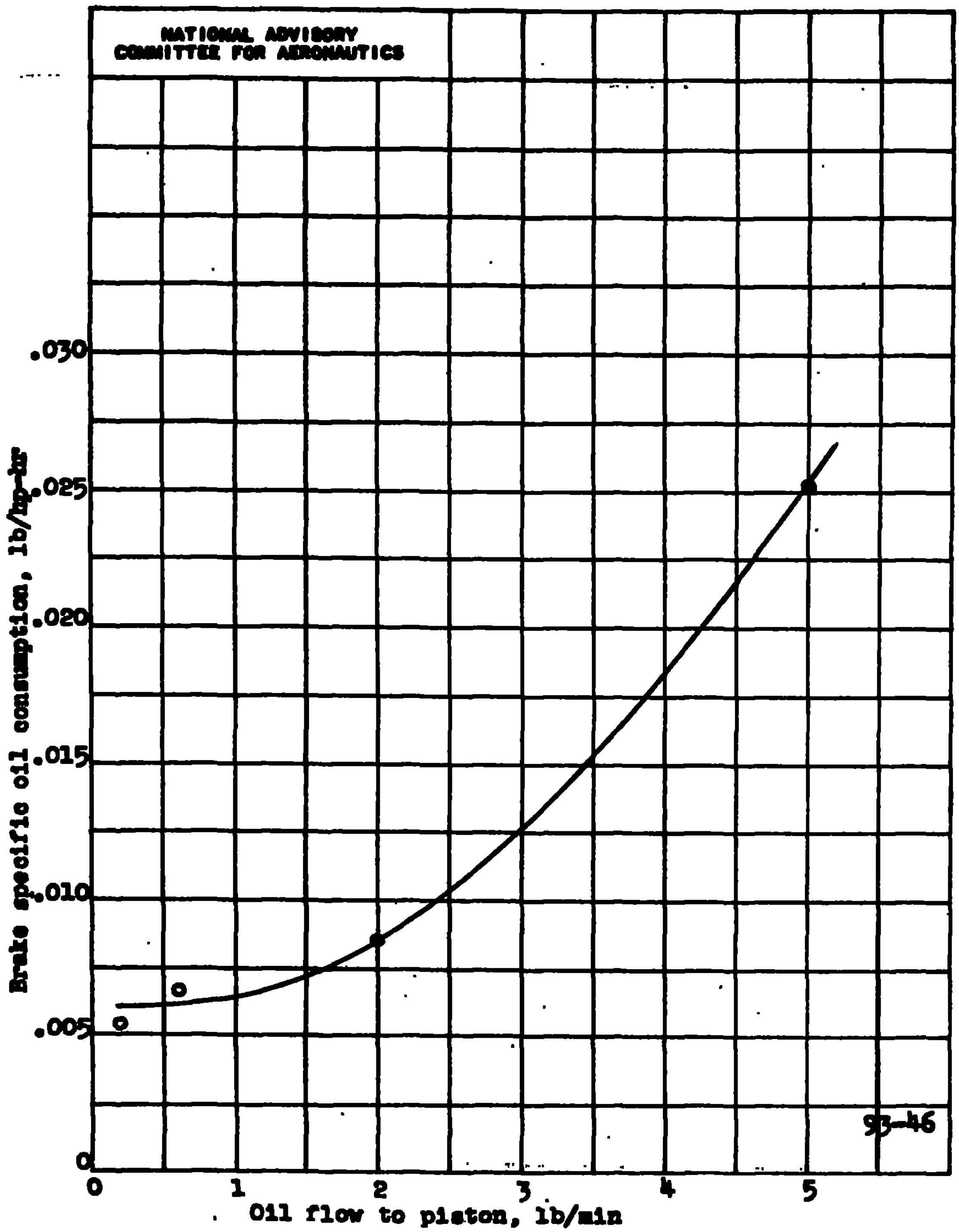


Figure 7. - Effect of the oil-flow rate to the piston on brake specific oil consumption, taken at the 6-hour point in each test. Cross plot of figure 7.